Original Contribution

Studies on the Mayak nuclear workers: health effects

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Aim of the study

The Mayak facility in Ozyorsk, Russian Federation, began operations in 1948 as the first and largest nuclear weapons facility in the former Soviet Union (Mayak Production Association, Mayak PA). The health studies on workers at the main Mayak plants have the potential to fill important gaps in radiation epidemiology. Both the external exposures and the plutonium exposures exceeded by far those of nuclear workers in other countries. Thus they offer the singular opportunity to provide reasonably precise quantitative estimates of risks from protracted exposure to external radiation and from internal exposure to plutonium. Both male and female workers were exposed. The resulting risk estimates can be compared with those from other sources, especially those from the atomic bomb survivors.

Description of the cohort

The cohort of workers at the three main Mayak plants (nuclear reactor complex, radiochemical plant, and plutonium production plant) included nearly 19,000 individuals who were hired before 1973. The characteristics of these workers by plant, are shown in Table 1 and are described in more detail by Koshurnikova et al. [*1*]. Workers in all three plants were exposed to external radiation; those in the radiochemical and plutonium plants were also exposed to plutonium. Exposures and incorporations of plutonium were highest during the early years of operation. For the 10,655 workers hired before 1959 who had been monitored for external radiation, the mean cumulated external dose was 1.2 Gy. About 1,100 workers had estimated plutonium incorporations that exceeded 1.5 kBq (40 nCi) and extended up to 172 kBq (4,662 nCi).

Problems, limitations, potential solutions

The assessment of excess cancer rates in an exposed cohort requires a comparison either with an appropriate external control group or with an internal low dose group. With the Mayak cohort, both these approaches present considerable difficulty. External comparisons in nuclear worker studies are difficult to interpret because of the "healthy worker effect". An additional difficulty is that the age-, calendar year-, and sex-specific rates for the Russian Federation are not sufficiently detailed for many specific cancers of interest. To address this problem, a method for imputing additional detail into

Russian rates has been developed. A better solution is to emphasize internal comparisons by level of dose, but a difficulty is the small number of workers with low doses among those hired before 1959. To strengthen dose-response analyses, the cohort has been expanded by adding about 2,700 low-dose workers who were not assigned to the three main plants, but were involved with mechanical repair and water treatment in Mayak.

Among the workers in the radiochemical and plutonium plants, i.e. among those with potential plutonium exposures, there are currently only 36% who have plutonium monitoring data. Several approaches are being used to address this problem:

- In the current approach to quantifying the risks of plutonium exposure, the analyses are limited to workers with monitoring data and to reactor workers (no plutonium exposure).
- Efforts are under way to extend the monitoring data by performing excretion measurements on workers who are still available and by examining medical records for any additional monitoring data they may contain.
- A plutonium surrogate variable is being developed that can be used to account for plutonium as a confounder in analyses aimed primarily at evaluating the effects of external exposure. In this way a considerable number of unmonitored workers can be included in these studies. In addition, efforts to quantify risks from external exposure will need to focus primarily on cancers other than lung, liver, and bone where the internal exposures are less important.

Major results

Dose-response relationships for exposure to external radiation have been demonstrated for leukemia, all solid cancers, and all solid cancers other than lung, bone, and liver cancer [2]. Risk estimates are uncertain to ascertain because of the still on-going work on the dosimetry, but the patterns of risk by sex, age at exposure, and time since exposure appear to be generally similar to those observed in A-bomb survivors.

Excess rates of lung, bone, and liver cancer have been clearly linked with plutonium exposure. Lung cancer risks have been studied by several investigators including Tokarskaya et al. [3], Koshurnikova et al. [4], and Kreisheimer et al. [5]. In the most recent of these analyses, Kreisheimer et al. [5] evaluated the risk of lung cancer as a function of dose from external exposure and internal exposure from plutonium. A highly significant association was demonstrated for internal exposure; for external exposure there was a trend with borderline statistical significance. The results are consistent with linear dose dependencies. For plutonium exposure the excess relative risk (ERR) per Sv at age 60 (with a radiation weighting factor of 20 for alpha particles) was estimated to be 0.6 (95%, CI: 0.4-1.0). For external dose, the ERR per Sv at age 60 was estimated to be 0.2 (95%, CI: -0.04 to0.7). Studies on bone and liver cancers have been performed by Koshurnikova et al. [6] and Gilbert et al. [7]. In these studies relative risks in the highest plutonium exposure category (estimated body burden >7.4 kBq) were estimated to be 7.9 (95%, CI: 1.6-32) for bone cancer and 17 (95%, CI: 8.0-36) for liver cancer. With the exception of the observation of 1 bone cancer in a group of 26 Los Alamos Manhattan Project workers [8], these studies are the first ones to present evidence based on human data of lung, bone, or liver cancers resulting from exposure to plutonium.

Future plans

Analyses making use of improved dose estimates for both external and internal exposure will be conducted. Risk estimates for leukemia, all solid cancers, and all solid cancers excluding lung, bone, and liver will be quantified as a function of dose from external exposure, which will include appropriate adjustment for internal exposures. Risks of lung, bone, and liver cancers will be quantified as a function of both external and internal dose. Other specific cancers will be evaluated for associations with external and internal exposure.